

# Different Types of Conflicting Knowledge in AmI Environments

Martin Homola<sup>1</sup> and Theodore Patkos<sup>2</sup>

<sup>1</sup> Comenius University in Bratislava  
Mlynská dolina, Bratislava, Slovakia  
<sup>2</sup> FORTH-ICS, Heraklion, Greece

**Abstract.** We characterize different types of conflicts that may occur in complex distributed multi-agent scenarios, such as in Ambient Intelligence (AmI) environments, and we argue that these conflicts should be resolved in a suitable order and with the appropriate strategies for each individual conflict type. We call for further research with the goal of turning conflict resolution in AmI environments and similar multi-agent domains into a more coordinated and agreed upon process.

## 1 Introduction

Ambient Intelligence (AmI) [21,11] is a challenging application domains for multi-agent systems, conceived initially to accommodate the ever increasing penetration of interconnected mobile devices into our everyday life. Ever since, AmI triggered a shift in computing towards developing more pervasive and sensor-rich environments, often referred to as smart spaces. Research in AmI places the human user at the center of attention aiming at creating intelligent environments with the ability to adapt to human preferences, serve their needs and goals, and communicate with their inhabitants utilizing novel means. This paradigm implies a seamless medium of interaction, advanced networking technology, and efficient knowledge management, in order to deploy spaces that are aware of the characteristics of human presence and the diversities of personalities, being also capable to respond intelligently and proactively to the users' needs.

AmI environments are populated with embedded computing devices, which can be abstracted as autonomous agents. These agents are instructed to estimate and evaluate the current situation and the perceived users' goals, as well as to cooperate, in order to best support users' needs. Such complex scenarios require the agents to resolve conflicts that may arise and to act in agreement [18].

In this paper, we look at the knowledge architecture of such systems and analyse the different types of conflicts that the agents may face: sensory input, context, domain and background knowledge, goal, and action conflicts. We argue that such conflicts should be resolved in a suitable order and using strategies appropriate for each given type. Moreover, conflicts cannot always be resolved by the agents independently; a certain level of consensus and agreement on conflict resolution needs to be pursued. This opens new research challenges in knowledge-based multi-agent systems and their application domains.

## 2 Ambient Intelligence

Zelka et al. [21] and later Aarts [1] devised the requirements, based on which AmI systems should be:

1. *embedded* within the environment: users do not need to be concerned with their operation,
2. *context-aware*: they are able to recognize the user and the situation,
3. *personalized*: able serve different users according to their own needs,
4. *adaptive*: they can change in response to the environment and users actions,
5. *anticipatory*: they should understand the users needs and act upon them pro-actively and not just in response to user's request.

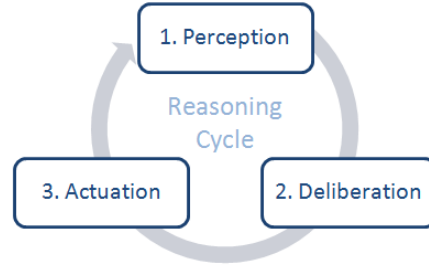
As a multitude of devices serving diverse purposes are typically installed in smart spaces, it is reasonable to assume that the agents may be rather heterogeneous in their implementation. Particularly, their cognitive skills may range from simple reactive agents whose behavior is based on the most recent sensor readings, to complex knowledge-based and deliberative agents that perform elaborate reasoning, in order to infer relevant context, make estimates over the users' intentions, and communicate and negotiate with the other agents in collaborative manner. Abstracting away details of implementation, we can generally assume such agents to possess at least the following components:<sup>3</sup>

- A knowledge base of some sort, comprising as a distinguished part the *context model* of the current situation respective to the agent, and possibly some additional background and domain knowledge. Each agent may keep track of different aspects of the world and represent them differently from the other agents.
- A set of *goals* the agent is able to follow to serve its purpose, from which it selects some subset, depending on the current perceived context.
- Either some predefined plans of *actions* to execute to achieve each goal or the ability to plan the actions accordingly when needed.
- Some means to *communicate* with other agents with the aim to exchange knowledge and cooperate (e.g., messages, queries, bridge rules, etc.).

It should be remarked that in AmI systems the general aim of an agent is to perceive and accommodate the goals of the users and to help them in carrying out actions to achieve these goals. For this reasons, users are likewise often modeled as goal-driven acting agents. This metaphor is indeed useful when studying AmI environments as a whole, however one must keep in mind that there is a distinction between the goals of an agent and goals of a user.

An abstract loop that can characterize the basic internal reasoning phases carried out by an agent is shown in Fig. 1 and involves the phases of perception, deliberation and actuation. This cycle is triggered by specific sensory inputs that the agent is monitoring (or the lack of them) and captures the ability to both deliberate about how best

<sup>3</sup> We take a pragmatic abstraction from the classical BDI agent architecture [17]: beliefs are stored in the knowledge base, desires are mapped as goals, and intentions allow the agent to map the current situation into a subset of goals to follow and actions to execute.



**Fig. 1.** Reasoning cycle of autonomous devices in smart spaces

to *interpret changes* that occur in their dynamically changing world, as well as to *make decisions* about the most appropriate course of actions that needs to be taken to support human users' activities. While many approaches have been proposed to study each phase alone, recent studies (e.g., [16,5]) argue about the need for a seamless integration of the tasks of perception, recognition and acting in a coherent loop, in order to synthesize support services in smart environments with proper and verifiable behavior.

In addition to its dynamic nature, the aspect of heterogeneity is an equally challenging factor for developing AmI services. Agents operating in smart spaces may have different reasoning skills, obtain access to distinct knowledge repositories, local or shared, and evaluate incoming information based on different trust criteria. A real-world smart system needs to respect the fact that the way context is inferred by each involved agent is not an objective process. Being highly distributed, these environments produce information that can be interpreted in a totally different manner by the various intelligent agents; and it is not uncommon for the agents to end up having incoherent and conflicting views of the current context.

### 3 Conflicting Knowledge

The importance of dealing with conflicts has been noted by other researchers working in AmI [18,10,14]. Resendes et al. [18] analyze different types of conflicts that may arise in AmI systems and organize them into a taxonomy, as listed in Table 1.

**Table 1.** Taxonomy of conflicts [18]

Dimension	Source	Intervenients	Detection time	Solvability
<b>Possible types</b>	resource	single user	a priori	conflict avoidance
	application	user vs. user	when it occurs	conflict resolution
	policy	user vs. space	a posteriori	acknowledge inability
	role			acknowledge occurrence

The authors identify four basic broad categories of conflicts, which are dubbed *dimensions*, in order to stress their orthogonality, i.e., the fact that one conflict can be

independently classified with respect to each of them. The *source* dimension indicates where/how each conflict originates – it may be the case that users (or applications) are conflicting over some resource allocation, or it is not possible to execute some action due to policy, or there are conflicting user profiles. Following the *intervenients* dimension, there might be conflicting intentions within a single user, between multiple users, or between user and the space. The *detection time* dimension sorts conflicts into those that are (can be) detected a priori, at the time they occur, or only a posteriori. Finally, the *solvability* dimension indicates at which level can conflicts be resolved – before they happen (i.e., to avoid them), immediately when they happen, or after some delay, in which case they are further split into those conflicts which cannot be resolved at all and those which cannot be resolved due to being detected too late.

The taxonomy of Resendes et al. is arguably very useful. In addition to this classification, though, and considering the agent architecture of AmI systems, it appears to us that conflicts should also be categorized based on the different types of knowledge in which they appear. This is due to the fact that each type of knowledge is processed differently, and in a different point of the agents reasoning cycle depicted in Fig. 1. This classification can be seen as yet another dimension, orthogonal to the previously discussed four, which we propose to add into the taxonomy of Resendes et al., as shown in Table 2 and described next:

**Table 2.** The knowledge dimension of conflicts

Dimension	Knowledge type
<b>Possible types</b>	sensory input
	context
	domain/background
	goal
	action

**Sensory input conflict:** if a conflicting reading of some sensors appears. This type may refer to multiple readings of the same or similar sensors or it may be the result of different sensors, whose outputs are mutually exclusive (the agents know that these outputs cannot occur at the same time). The conflict may arise within a single agent, but it may also be distributed between more than one agent (each containing part of the conflicting readings). The latter option may subsequently cause a contextual conflict.

**Contextual conflict:** if two (or more) agents are part of the same situation, their models of the world may be conflicting, implying, e.g., a different location, or perceived activity of the user, etc. This type of conflict is may be caused by a previous unnoticed sensory input conflict, but also by a different evaluation of the situation.

**Domain and background knowledge conflict:** domain and background knowledge refer to the information the agent possesses and uses, in order to fulfill its purpose. Conflicts in these types of knowledge, if they occur, may require a different kind of solution. In contrast with contextual information which is dynamic and changing, domain and background knowledge are often considered unchanging and fully

specified (to the extent required by the application). Hence, redesign of the agent's knowledge base by its creator may be required, rather than resolving the conflict in an automatic manner.

**Goal conflict:** if two (or more) agents are part of the same situation, their models of the world are compatible, but they have mutually conflicting goals. Note that we do not consider it a goal conflict if agents have conflicting goals in different models of the world, because it is natural to have different goals in different situations.

**Action conflict:** if two (or more) agents share a compatible model of the world, and a compatible set of goals, however, they decide to undertake a conflicting course of actions to carry out their goals.

## 4 Discussion

The ability to efficiently deal with conflicts is imperative, in order to appropriately balance between the two main design principles that have been set for the success of AmI systems: being as less intrusive as possible with minimal need for human intervention, while still allowing users to feel confident that they are in control. Devising intelligent automated mechanisms for identifying, preventing or resolving conflicts is of utmost importance in this area of research.

Compared with the classic BDI architecture, the proposed knowledge type dimension is more fine grained: the agent's representation of sensory inputs, context, and domain/background knowledge are all different types of beliefs. As we argued, it is important to distinguish between them because they are resolved differently, and in different time. For instance, together with the two additional knowledge types they can be sorted on the scale from lower to higher level of knowledge: (a) sensory input, (b) contextual, domain and background knowledge, (c) goals, and (d) actions, in the respective order. Distinguishing between these five types is important also due to the following conjecture: solving conflicts in a lower level knowledge can reduce and may possibly prevent occurrence of further conflicts in the higher levels of knowledge. For example, if two agents have a conflict in the contextual knowledge, that is, their interpretation of the situation in which they both participate is not compatible (e.g., they may have conflicting information about location) – if the conflict is resolved at this level, it is less likely that the agents will come up with conflicting goals and consequently action plans.

Due to different nature and complexity of conflicts at the different knowledge types, different formalisms and tools are suitable to resolve each type of conflict in this respect. Sensory conflicts are probably most effectively resolved with use of repeated and redundant readings which are then cleaned using statistical methods [12]. Hybrid approaches that combine statistical methods with reasoning were applied on resolving contextual conflicts (e.g., for identifying the user's situation [20]). As we noted above, conflicts in domain and background knowledge most likely require a manual solution.

As noted above, a number of higher level conflicts can likely be prevented by timely identification and resolution of conflicts at lower levels. The remaining goal and action conflicts are more intriguing. While approaches such as multi-context systems [9,3] allow to build agents capable to deliberate on knowledge obtained from other agents [19,2], the conflict resolution process is typically confined within an agent, and executed

independently from the other agents. Two independent agents may thus resolve the same conflict differently without a deeper consensus, resulting into ill-coordinated action. This points out that further investigations are needed in order to develop multi-agent architectures with consensual and cooperate conflict resolution. Few existing works [8,2,13,4] show a prospective path by incorporating results from areas such agreement technologies [15], argumentation [7], computational social choice [6], etc.

*Acknowledgements.* This work resulted from the Slovak–Greek bilateral project “Multi-context Reasoning in Heterogeneous environments”, registered on the Slovak side under no. SK-GR-0070-11 with the APVV agency and co-financed by the Greek General Secretariat of Science and Technology and the European Union. It was further supported from the Slovak national VEGA project no. 1/1333/12. Martin Baláž and Martin Homola are also supported from APVV project no. APVV-0513-10.

## References

1. Aarts, E., Harwig, R., Schuurmans, M.: Ambient intelligence. In: Denning, P.J. (ed.) *The Invisible Future: The Seamless Integration of Technology into Everyday Life*. McGraw-Hill Companies, New York (2001)
2. Bikakis, A., Antoniou, G.: Defeasible contextual reasoning with arguments in ambient intelligence. *IEEE Transactions on Knowledge and Data Engineering* 22(11), 1492–1506 (2010)
3. Brewka, G., Eiter, T.: Equilibria in heterogeneous nonmonotonic multi-context systems. In: *AAAI* (2007)
4. Brewka, G., Eiter, T.: Argumentation context systems: A framework for abstract group argumentation. In: *LPNMR* (2009)
5. Chen, L., Khalil, I.: Activity recognition: Approaches, practices and trends. In: *Activity Recognition in Pervasive Intelligent Environments*, Atlantis Ambient and Pervasive Intelligence, vol. 4, pp. 1–31. Atlantis Press (2011)
6. Chevalere, Y., Endriss, U., Lang, J., Maudet, N.: A short introduction to computational social choice. In: *SOFSEM* (2007)
7. Dung, P.M.: On the acceptability of arguments and its fundamental role in nonmonotonic reasoning, logic programming and n-person games. *Artificial Intelligence* 77, 321–357 (1995)
8. Ferrando, S.P., Onaindia, E.: Defeasible argumentation for multi-agent planning in ambient intelligence applications. *AAMAS* (2012)
9. Giunchiglia, F.: Contextual reasoning. *Epistemologia*, special issue on *I Linguaggi e le Macchine* 16, 345–364 (1993)
10. Henriksen, K., Indulska, J.: Modelling and using imperfect context information. *PERCOMW* (2004)
11. Information Society Technologies Advisory Group (ISTAG): *Ambient Intelligence: from vision to reality* (2003)
12. Lu, C.H., Fu, L.C.: Robust location-aware activity recognition using wireless sensor network in an attentive home. *IEEE T. Automation Science and Engineering* 6(4), 598–609 (2009)
13. Moraitis, P., Spanoudakis, N.: Argumentation-based agent interaction in an ambient-intelligence context. *IEEE Intelligent Systems* 22(6), 84–93 (2007)
14. Ortega, A.M., Blaya, J.A.B., Clemente, F.J.G., Pérez, G.M., Skarmeta, A.F.G.: Solving conflicts in agent-based ubiquitous computing systems: A proposal based on argumentation. In: *Agent-Based Ubiquitous Computing*, vol. 1, pp. 1–12. Atlantis Press (2010)
15. Ossowski, S. (ed.): *Agreement Technologies*. Springer (2013)

16. Pecora, F., Cirillo, M., Dell'Osa, F., Ullberg, J., Saffiotti, A.: A constraint-based approach for proactive, context-aware human support. *JAISE* 4(4), 347–367 (2012)
17. Rao, A.S., Georgeff, M.P.: Modeling rational agents within a BDI-architecture. In: *KR* (1991)
18. Resendes, S., Carreira, P., Santos, A.: Conflict detection and resolution in home and building automation systems: a literature review. *J. Ambient Intelligence and Humanized Computing* 5(5), 699–715 (2014)
19. Sabater, J., Sierra, C., Parsons, S., Jennings, N.R.: Engineering executable agents using multi-context systems. *J. Log. Comput.* 12(3), 413–442 (2002)
20. Ye, J., Dobson, S., McKeever, S.: Situation identification techniques in pervasive computing: A review. *Pervasive and Mobile Computing* 8(1), 36–66 (2012)
21. Zelkha, E.: The future of information appliances and consumer devices. In: Palo Alto Ventures, Palo Alto, California, (unpublished document) (1998)